Spring 4-29-2024

Prescription for Prosperity: The Dual Miracle of Antiretroviral Therapy and African Growth

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29th April 2024

Abstract

This paper investigates the effect of antiretroviral therapy (ART) coverage on economic growth in Sub-Saharan Africa. I model the relationship following the expanded Solow Growth Model, proposing a dual health capital and educational human capital mechanism through which ART impacts growth. While previous studies propose conflicting results, I use the most comprehensive dataset, and employ theory-backed specifications to provide the most accurate and reliable estimates of the effect. Using a panel of all 48 countries in Sub-Saharan Africa, I employ a two-stage least squares shift-share/Bartik instrumental variable approach, including two-way fixed effects to estimate the effect of a rapid expansion of ART coverage on economic growth between 2001 - 2019. I show that, contrary to previous estimates, ART coverage does not have a significant effect on economic growth. While naive estimates suggest a significant relationship, these results are not robust to various specifications. I posit possible reasons for the difference to previous estimates.

[1] **Acknowledgments**

I would like to thank my advisor, Dr. Mario Solis-Garcia, for his unwavering support and guidance throughout this project. I would also like to thank Dr. Amy Damon and Professor Vanessa Voller for their invaluable expertise and advice. I am grateful to my peers Anna Durall, Ghaicha Aboubacar Ahe, Mahmoud Majdi, Mateo Useche Rosania, and Zak Yudhishthu, for their support and camaraderie. Finally, I am grateful to my family, friends, and mentors for their support throughout my undergraduate studies and beyond.

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1. Introduction

The HIV/AIDS[2] epidemic has been one of the most devastating epidemics in modern human history and continues to be a leading cause of death worldwide. Approximately 85.6 million people have been infected with the disease since the beginning of the epidemic and there have been a reported 40.4 million HIV/AIDS-related deaths worldwide (UN AIDS, 2023). An estimated 39 million people were living with HIV/AIDS in 2022 (UN AIDS, 2023). While the epidemic has been widespread, there are significant variances in the outcomes and public health responses to the epidemic. Sub-Saharan Africa, one of the least economically developed regions on earth, has been disproportionately affected, accounting for an estimated 67% of global HIV rates in 2021 and 230,000 of the 650,000 AIDS-related deaths reported globally in 2021 (Moyo et al., 2023).

While HIV remains a leading cause of death, especially in Sub-Saharan Africa (Statistica, 2020), hope remains for the eradication of the disease. New infections have decreased by 59% since its peak in 1995, with deaths decreasing by 69% since the peak in 2004 (UNAIDS, 2022). This is in large part due to the introduction of antiretroviral therapy (ART)[3], a treatment of HIV. Since the emergence of ART in the early 2000s, it has proven to be revolutionary in the fight against an incurable disease, with regional studies finding that treatment including ART leads to a 30% lower level of HIV incidence than standard care (Hayes et al., 2019).

The emergence of ART across the continent was simultaneously met with a surge in per capita economic growth rates, resulting in a period dubbed the "African growth miracle"

[2] "Human immunodeficiency virus (HIV) is an infection that attacks the body's immune system. Acquired immunodeficiency syndrome (AIDS) is the most advanced stage of the disease" (WHO, 2023)
[3] Antiretroviral therapy is a treatment of HIV/AIDS using a combination of viral-load suppressing drugs (NIAID, 2024)

(Pinkovskiy and Sala-i-Martin, 2014; Rodrick, 2018). This prompts the question**:** what is the effect of the rapid increase in Antiretroviral therapy (ART) provision on economic growth in Sub-Saharan Africa?

To address this question, I employ both macroeconomic modeling and empirical methods to build a comprehensive and multi-methodological investigation of the topic. Building off previous studies, I construct an expansion of the Solow growth model and posit a dual mechanism approach to model causality. I test this model analyzing data from 48 countries in Sub-Saharan Africa over 19 years to establish the impact of ART provision on economic growth.

To limit the potential endogeneity that I explain later, I construct an instrument following Tompsett (2020) in order to run a shift-share instrumental variable approach. I hypothesize that the relatively recent expansion of access to ARVs, due to a substantial decrease in their cost in Sub-Saharan Africa results in increased economic growth in the region

2. Literature Review

Having established the extent of the HIV/AIDS epidemic, concentrated in Sub-Saharan Africa, I now present studies that examine the effect of human health and, more specifically, HIV/ART on various aspects related to my question, narrowing until I reach the papers closest to my own.

Human health is an important input to economic performance and growth. Ashraf et al., (2008) find that an increase in the general health of populations leads to a very modest increase in GDP per capita and that these increases take several decades to be realized.

The effect of HIV/AIDS on macroeconomic conditions has been studied in an attempt to test theories and assumptions. Some studies specifically focus on the impact of HIV on economic growth. MacDonald et al., (2006) find that an increase in HIV prevalence by 1% results in a 0.59% decrease in income per capita. At the same time, Ahuja et al., (2006) find that HIV has no significant impact on economic growth, but results in a decline in fertility combined with a slow-down in education gains, as measured by youth literacy, and a rise in poverty, as measured by malnutrition (Ahuja et al., 2006).

Bonnel (2000) built a three-equation model, looking at 1) the link between economic growth and macroeconomic policy, institutions, and other determinants of growth, 2) the link between potential instrumental variables and HIV, and 3) the determinants of HIV prevalence. Bonnel's results indicate that the effect of AIDS on economic growth is significant only for countries that have a high HIV prevalence, which he estimates to have a 2.6% decrease in economic growth for every additional percentage increase in HIV prevalence of the population.

ART has proven to be an incredibly effective treatment for HIV, with ART provision leading to rapid increases in life expectancy across hard-hit regions, as well as several other development indicators (Baranov, 2018). Dadonaite (2017) finds that by 2016, the global mortality rate of ART had been halved as a result of the provision of ART. Infected people not receiving ART rarely live 10 years past infection, but now, people in high-income countries who started ART in their 20s can now expect to live well into their 60s, and this number is only increasing (Dadonaite, 2017).

The increase in life expectancy alone has several effects on life cycle decisions (Baranov, 2018). Additionally, a longer life expectancy increases the value of human capital investment (Baranov, 2018), thus affecting how different types of work and experiences relate to productivity, and thus economic growth.

The research that is closest to my own is done by Tompsett (2020) who employs panel data from 90 low-and-middle-income countries between 1990 and 2014 (although ART data is only available from 2001 onwards in most countries) to measure the effect of ART on economic growth empirically. The study finds that ART provision has a positive effect on economic growth. Specifically, she finds that on average in the sample of 90 countries, an increase in ART coverage by 1% of the population results in an approximate 1.4 percentage points increase in GDP growth/capita. Crucially, Tompsett (2020) also investigates this effect specifically in Sub-Saharan Africa and estimates the effect to be 1.25% when the sample is limited to the region.

Similarly, (Rubio, 2012) investigates the effect of antiretroviral therapy on the dynamics between HIV/AIDS and economic growth, specifically in Sub-Saharan Africa. Rubio employs a macroeconomic modeling and empirical hybrid approach. In the modeling approach, Rubio builds an extended version of the Solow growth model, whereby he adds a human capital variable in terms of investment in education as well as in terms of health. This results in a growth equation derived from the augmented Solow model, and a reduced-form health equation. To combat his concerns regarding endogeneity, bias, and heterogeneity, Rubio uses an instrumental variable approach, where the specific instrument is the price of ART. Rubio concludes that the HIV/AIDS epidemic reduces GDP per capita by 0.175% per marginal percentage increase in HIV prevalence. He also finds that ART provision increases GDP per capita by 0.048% per percentage increase in ART provision (Rubio, 2012).

My contribution to the literature is three-fold. First, I propose a new way of modeling the effect of ART on economic growth, expanding upon previous attempts to model this using the Solow Growth Model. Second, I utilize the most accurate and comprehensive dataset on the topic as I discuss in the data section, in order to claim the most representative study on this topic. Finally, I employ theory-backed dependent variables, opting not to simply use the dependent variables used in the studies discussed above. The motivation is therefore to conduct the most comprehensive analysis of the topic, providing a final estimate to a contested relationship.

Before continuing, I must make a distinction in the purpose of this paper. It is understood and appreciated that antiretroviral drugs were engineered as a treatment to improve the health of those living with HIV/AIDS. The right to health is covered under several international treaties (WHO, 2023). This study does not serve to argue for the use of ART as a tool for economic growth policy. Nor does it attempt to provide a comprehensive review of the effect of ART on health and humanitarian outcomes. Instead, it attempts to model and estimate the effect of a drastic increase in the provision of ART on a period of substantial growth on the continent.

3. Context

While the origins and early spread of HIV are conflicted, with some theories suggesting unsanitary colonial vaccination programs contributed to the rapid spread of the disease across the continent (Vance, 2019), the verifiability of such theories remains limited. Besides, that is entirely beyond the scope of this paper. It is important to acknowledge however that the origins and early spread of the virus both have extremely important implications, not only for ethical and/or historical reasons but also for the economic and political question of who should be responsible (in time and resources) to respond to the epidemic.

Since its initial spread in the 1990s, the region has been ravaged by a deadly virus. By 2002, the adult HIV prevalence was approximately 1.2% worldwide, while in Sub-Saharan Africa, it stood at 9% (Goliber, 2002). Eswatini, the country with the highest level of HIV/AIDS in the world, currently stands with an adult prevalence of 27.9% (The World Bank, 2024). The southern and eastern parts of the continent have a particularly high prevalence of HIV, resulting in the term “AIDS belt” being used in its reference (Goliber, 2002).

HIV transmission occurs through bodily fluids including blood and semen, predominantly through anal or vaginal sex, or the sharing of needles and other drug injection equipment (CDC, 2022). Causes for the high spread of HIV in Africa include high levels of poverty preventing people from prevention, testing, or treatment, inadequate medical care, lack of prevention and education, taboo and stigma, polygamy, and promiscuity practiced in parts of the continent, widespread prostitution, and sexual violence against women (SOS Children’s Villages, 2024). The spread has also been linked to migration (Docquier et al., 2014), further complicating the ability to measure the impact of ART on growth, due to the possible link between migration and income/growth.

While prevention has largely remained limited to traditional methods of contraception, male circumcision, and antenatal care (Martin, 2017), the introduction and subsequent expansion of ART programs across the continent has become the greatest combattant to the deadly disease. ART is often taken as a combination or “cocktail” of drugs that prevent the virus from replicating in the body, therefore allowing the immune system to repair itself (NHS, 2021). Studies have shown that a strict regimen of ART can suppress viral loads to undetectable levels, even resulting in the disease becoming untransmittable through sexual activity (NIAID, 2019). ART is extending and improving the lives of people living with HIV to live relatively long and healthy lives (Baranov, 2018).

There have been more recent developments in the prevention of HIV with the development and roll-out of a specific type of antiretroviral drug: pre-exposure prophylaxis or

PrEP,[4] which has proven to be more than 99% effective in preventing the spread of HIV and is effective in treating it (Arana, 2020). While PrEP is finally becoming more accessible for high-risk people in Sub-Saharan Africa (Irungu & Baeten, 2020) and has the potential to revolutionize the response to the epidemic, this study focuses on the effect of combination ARVs, known as ART, due to its long-term presence in the region.

At the same time as the expansion of the ART programs, there was another phenomenon occurring. Africa's decades-long growth rate has remained low and stagnant, with real per capita growth rate remaining at around 1.1%. However, between 2000 - 2010, this spiked to 5.1%, and then tapered off at 3.3% between 2010 - 2019 (Kuyoro et al., 2023). Since 2000, real household consumption in sub-Saharan Africa has grown between 3.4 and 3.7 percent per year (Young, 2012). This phenomenon has been dubbed the "African Growth Miracle", due to the period's high growth relative to previous estimates (Pinkovskiy and Sala-i-Martin, 2014; Rodrick, 2018).

While outside the scope of this paper, it is important to note that ART was developed and proven to be effective far before its roll-out on the African continent. Large pharmaceutical companies, notably Pfizer, acted as a monopoly in the industry, keeping prices high. An annual supply of ART sold for approximately $15,000 – far more than what the average African earned. Additionally, these companies prevented (through legal action) the importation of generic ART medication to protect the industry. In fact, it took thousands protesting in the streets of South Africa for the pharmaceutical companies – and governments who refused to import generic alternatives – to allow for the importation and free distribution of generic ART from India (MSF UK, 2021). The effort was branded "among the greatest-ever public health achievements in the

[4] PrEP has been a more recent development in ART biotechnology and has only recently been introduced in mass on the African continent, which is why I chose to study total ART.

history of humankind" by Eric Goemaere, an MSF doctor who served on the frontlines of South Africa during the peak of the epidemic (MSF UK, 2021).

My contribution to the literature is threefold. First, my proposed dual mechanism attempts to explain the effect of ART on economic growth in a new and more nuanced way. Second, my study includes the greatest number of Sub-Saharan African countries over the greatest number of years and specifically limits the context to Sub-Saharan Africa, therefore making it the most comprehensive attempt at estimating this causal relationship on the continent. Third, as I show later on, my use of GDP growth and ln(GDP) as dependent variables, instead of a change in ln(GDP) ensures the most accurate and externally valid study of the topic.

For all preferred specifications, I find statistically insignificant results. My results therefore suggest that ART coverage does not have a significant effect on economic growth. While naive estimates suggest a significant relationship, these results are not robust to various specifications. I posit possible reasons why my results differ from previous estimates.

4. Theory

In this section, I develop the structural growth equation that I use to model the effect of ART on economic growth. The building of the model follows the chronological order of the contributions to the model. I then pose a further expanded version of the model that addresses the issues raised in previous iterations.

4.1 Expanded Solow Growth Model

I start by outlining the Solow Growth Model (hereafter SGM), developed by Robert Solow (1956). The long-run economic growth model attempts to explain long-run economic growth through capital accumulation, labor or population growth, and productivity, which is driven by technological progress.

The textbook version of the Solow model follows:

$$Y = A_t f(K, L) \quad \textbf{(1)}$$

Where: Y = income, A = level of technology at time t, K = capital, L = Labor, and f() represents a production function.

This basic textbook form of the SGM indicates that income, and therefore economic growth of a country is a function of, and therefore dependent on, the inputs of labor and capital, as well as the level of technology at the time. Capital and labor are the most basic inputs of production and are therefore necessary in any growth model. The level of technology is important here as it drives productivity, and even revolutionizes productive processes.

With economists critiquing the SGM's ability to account for the international variation in income, the model was expanded by Mankiw, Romer, and Weil (1992) to include a human capital input, in addition to the physical capital input, and takes the following form:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta} \quad \textbf{(2)}$$

Where H(t) represents a human capital input, and the indices simply imply constant returns to scale.

This resulted in the model providing a better fit of the income data at the time (Mankiw et al., 1992), omitting the concerns of many that resulted in a shift away from the SGM and toward endogenous growth theory.

Knowles and Owen (1994) extend the model further, incorporating a health capital variable, as well as an education capital variable, replacing Mankiw et al. (1992)'s use of education capital as a proxy for total human capital. They outline the augmented SGM as the following:

$$Y_{it} = K_{it}^{\alpha} E_{it}^{\beta} X_{it}^{\psi} (A_{it} L_{it})^{1-\alpha-\beta-\psi} \quad \textbf{(3)}$$

Where E is the stock of education capital, and X is the stock of health capital.

3.2 Dual Mechanism Approach

I propose using this framework to model the effect of ART on economic growth. The model proposed by Knowles and Owen (1994) has been used to explain the impact of ART on economic growth, using the added health capital variable as the mechanism by which ART impacts growth. My addition to the methodological literature is the attempt to model the effect of ART provision on economic growth through two primary mechanisms:

1. A direct health capital method
2. An indirect education capital method

In this sense, I expand the education capital variable to include all formal education, as well as training, workshops, skills programs, etc.

The direct health capital mechanism: ART allows people to live longer and more normal lives, and thus allows people to engage in productive activities for a greater period of time throughout their lives. This has a direct increase in productivity, and therefore economic growth.

The indirect education human capital mechanism: increased life expectancy and ability to work longer careers results in an increase in the return on education and the investment in education. HIV-positive people receiving ART are able to put their education and training to use, instead of being too sick to work, or even dying early.

Therefore, I argue that ART does not just influence economic growth through a single variable in the Cobb-Douglas production function, but rather through both health and education capital variables in the augmented Solow Growth Model. The feedback between health and education capital is an essential assumption in this model.

To illustrate the mechanics of the relationship between ART provision and economic growth, I write out the relationship as follows:

$$\frac{\partial Y}{\partial ART} = \frac{\partial Y}{\partial X} \cdot \frac{\partial X}{\partial ART} + \frac{\partial Y}{\partial E} \cdot \frac{\partial E}{\partial X} \cdot \frac{\partial X}{\partial ART} \quad (4)$$

Where $\frac{\partial Y}{\partial ART}$ is the change in income due to a change in ART coverage, $\frac{\partial Y}{\partial X} \cdot \frac{\partial X}{\partial ART}$ is the direct effect of ART on income through the health capital variable, and $\frac{\partial Y}{\partial E} \cdot \frac{\partial E}{\partial X} \cdot \frac{\partial X}{\partial ART}$ is the indirect effect of ART on income through the education capital variable

What previous studies have assumed is that there is no feedback between health capital and education capital, or technically speaking, $\frac{\partial E}{\partial X} = 0$. I argue that this is non-zero and that this explains the currently ambiguous effects of ART on economic growth.

We can think through this model intuitively. Consider an individual who gets diagnosed HIV-positive in their 20s. Assuming the individual does not seek treatment, they will slowly become ill over the next few years, and then, due to a weakened immune system, be susceptible to diseases. Within a few years, the person will be too sick to continue working and will in a matter of years, die due to an AIDS-related illness. The individual 1) has lived a shorter-than-natural life and has had a short career, therefore not remaining productive or contributing to the economy, due to the HIV/AIDS, and 2) the individual has not been able to use their education and training for long before falling too ill to work. This reduces the time that the individual would have benefitted from their education. On the other hand, if the individual is diagnosed in their 20s, and (assuming availability and affordability) immediately start their ART treatment, they are generally able to live well into their 40s, 50s, or beyond, which is on par with national average life expectancies. This results in them working a full career, and having the time to benefit from their educational opportunities. We would therefore expect that this person would have contributed far more to the economy than those who are not able to work far past diagnosis.

Assuming a negative relationship between HIV rates and economic growth rates, this model suggests that, ceteris paribus, an increase in ART coverage is reflected in both an increase in health capital and an increase in educational human capital (due to an increase in returns of investment in education), thus resulting in an increase in economic growth. It too suggests that previous estimates of this effect may be downwardly biased.

5. Data

While modeling this issue provides us with key insights, and allows us to explain, and even hypothesize how changes in ART may affect economic growth, we need to employ empirical econometric methods to test these hypotheses and provide magnitudes to this otherwise conceptual project. To do so, I extract the World Development Indicators (WDI) from the World Bank Databank to construct my data. The WDI is a compilation of high-quality, comparable indicators on various aspects and sectors of development that span 217 economies, over 50 years, and include 1,400 time series indicators. The data are annualized at the country level, as is the entirety of my analysis.

The panel that I use consists of all 48 Sub-Saharan African countries from 2001 to 2019, resulting in 840 observations. 2001 was chosen as the starting year due to the significant increase in ART coverage in 2001, resulting in a non-negligible proportion of HIV-positive people receiving ART. 2019 was chosen as the ending year due to the seismic disruption of COVID-19 on the ability to measure causal effects on economic growth.

My independent variable of interest is the instrument that I constructed which predicts ART coverage in countries using a regional average of ART coverage and the HIV prevalence in 2001 for each country. My dependent variable of interest is a measure of economic growth. Specifically, I am using a measure of GDP per capita, taken in 2017 Purchasing Power Parity (PPP) measured in international dollars[5] (henceforth GDP per capita). I use this measure to account for both changes in price levels across time (inflation) as well as any effect on currency fluctuations.

Table 1 presents descriptive statistics of a selection of key variables.

Table 1: Descriptive Statistics

VARIABLES	**N**	**mean**	**sd**	**min**	**max**
GDP per capita	1,130	4,749	5,656	584.1	35,689
Instrumented ART	1,056	.014	.0261	0	.176
ART coverage	1,012	26.25	26.83	0	98
GDP growth (annual %)	1,148	3.971	5.577	-46.08	63.38
Life expectancy at birth	1,152	57.87	6.992	18.39	77.24
HIV Rate (2001)	48	5.290	6.711	0	25.90
Number of Countries	**48**	**48**	**48**	**48**	**48**

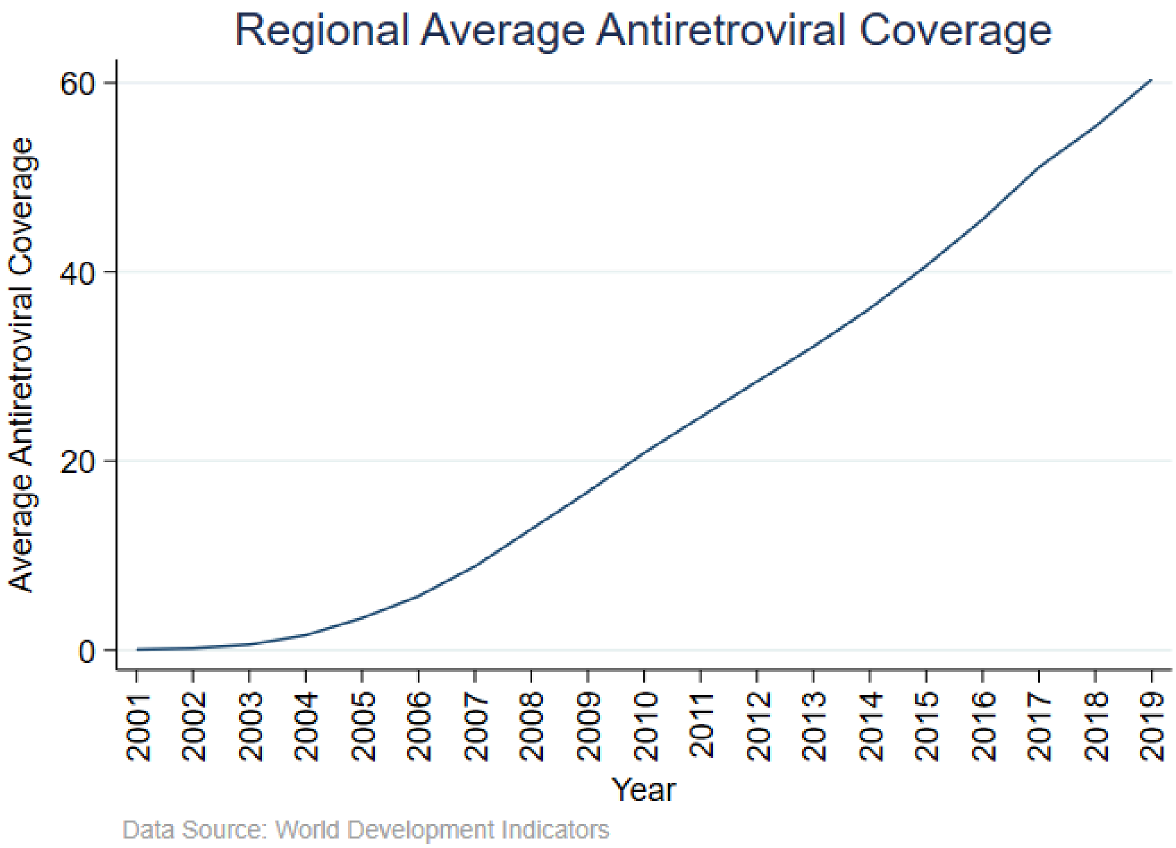
Table 1 highlights summary statistics of key variables in my dataset, providing both context and insight to the project. In particular, GDP per capita has a significant range of values, with $584.10 being the minimum and $35,689.00 being the maximum, highlighting the diverse

[5] GDP taken at 2017 PPP measured in international dollars was used to control for both price and currency fluctuations.

range of income within Sub-Saharan Africa. The mean and range of GDP growth further reveal the tale of inequality across countries. A growth rate of approximately 4% indicates generally strong economic performance across the continent. The range from -46% to 63% is almost difficult to believe, as these are very rare growth rates in the literature, and they help to contextualize how might be best to approach this problem empirically. Critically, the instrumented value of ART, with a range of 0 - .176 shows the effect of the construction of the instrument in assigning exogenous variation - at a far more narrow scale than measured ART coverage. Average life expectancy. At 57.87 years, and a minimum life expectancy of 18.39 years reflect the serious humanitarian concerns across much of the continent. A wide range of 2001 HIV rates indicates the very different situations that countries were in as the price of ART fell, and response drastically improved.

Figures 1 and 2 below present representations of a regional average of ART coverage and economic growth measure (GDP per capita taken at 2017 PPP in international dollars) respectively. ART coverage only became non-zero in 2001, as the earliest rollout of the region occurred that year, while GDP per capita is measured over the period 1998 - 2021, which represents all available relevant data at the time of writing. It is important to get a visual representation of these trends over the studied time period before attempting to estimate causal effects.

Figure 1: The Trend of ART Coverage Between 2000 - 2022



It is worth noting that the regional average of ART coverage has grown at a relatively stable rate since the mid-2000s with very little variation afterward. A relatively stable increase in ART coverage, despite fluctuations in economic growth as seen in **Figure 2**, makes me further question the effect that I am attempting to estimate.

Figure 2: The Trend of GDP pc (PPP, 2017 International Dollars)

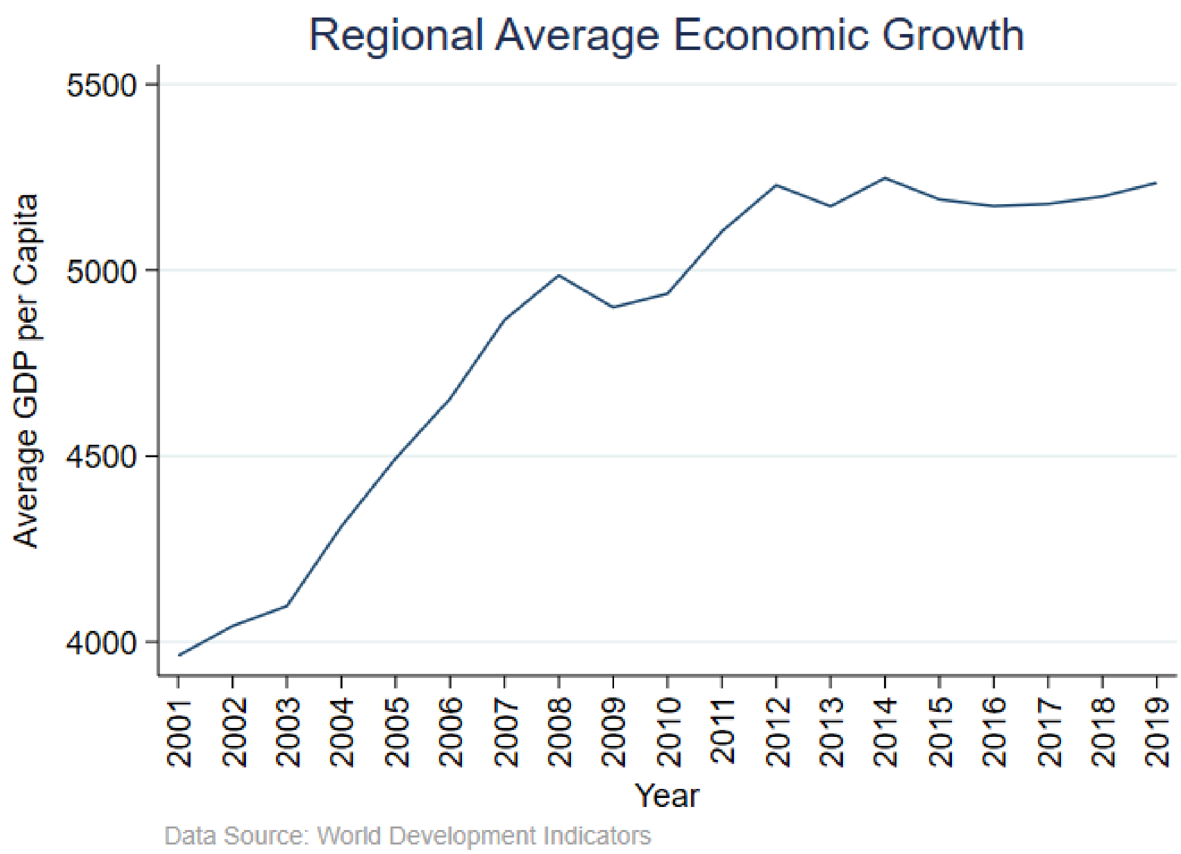


Figure 2 presents an interesting picture. There are three notable periods. From 1998 until 2008, economic growth was relatively high and even accelerating. From 2009 until 2019, economic growth becomes very unstable, and even plateaus. From 2020 until 2022, GDP per capita is increasing after a relatively large drop in 2020. Global events such as the global financial crisis of 2008 and the COVID-19 pandemic of 2020 are likely culprits of the times of major change as represented in Figure 2. Given these structural breaks, I examine these periods both separately and together to understand how the relationship between ART coverage and economic growth holds over different periods.

6. Empirical Strategy

My objective in employing these data is to understand the relationship between ART coverage and economic growth. There are two major threats to establishing causality: the possibility of endogeneity and the likelihood of omitted variable bias. Endogeneity describes a phenomenon whereby a two-way causal relationship exists between the dependent and independent variables. This results in the independent variable being correlated with the error term, biasing the estimated effect of the endogenous regressor. In this case, endogeneity is a concern if there exists a two-way causal relationship between ART coverage and economic growth. However, one could also argue that countries that experience higher economic growth may also have higher rollout of ART across the country. Or, if aid is often sent to low-economic-growth countries to combat the epidemic, the estimates would be measuring this selection rather than the causal effect. Further, it could be the case that HIV and the health structures are related to growth, resulting in endogeneity. These scenarios, while simply a few examples, explain how intertwined the concepts of economic growth, aid, healthcare provision, and ART coverage are. It is therefore difficult to estimate the effect of ART coverage on economic growth using an Ordinary Least Squares (OLS) method, as estimates are bound to be biased.

To address this, I employ a Two-Stage Least Squares (2SLS) instrumental variable technique in order to isolate the effect of ART coverage on economic growth. I specifically use a Bartik, or shift-share, instrumental variable approach: an approach used in development economics, including in (Kasahara et al., 2020). It is constructed by multiplying the annual regional average of ART coverage and the rate of HIV prevalence in each country in 2001, thereby capturing the effect on economic growth caused only by the decrease in the cost of ART, rather than other country-specific factors that affect the coverage of ART. The effect of this can be explained in two parts: the “shift” comes from the regional average of ART, while the “share” aspect refers to the initial value of HIV in 2001 within and specific to each country. Crucially, the shift-share assumes that the local change in ART can be explained by 1) regional trends (the shift) that represent the general impact that ART has across the entire population and 2) local composition (the shares) which reflect the specific characteristics of the country that makes it more or less responsive to the regional (continental) trend. By combining these effects, the instrument provides a predicted value of the country-level ART coverage which can then be compared to the actual observed value to estimate the causal effect of ART on economic growth. Further, this instrument no longer suffers from the endogenous properties of observing ART coverage at the country level directly.

Formally, we construct the instrumental variable (ART_{pred}) by multiplying a regional average of ART coverage ($ART_{regional}$) with the rate of HIV prevalence in the respective country in 2001 (HIV_{2001}). This can be expressed as:

$$Pred(ART)_{it} = \varphi_0 + \varphi_1(Avg(ART)_t \cdot HIV_{i,2001}) + \alpha_i + \delta_t + \varepsilon_{it}$$

(5)

Where $Pred(ART)_{it}$ is the constructed predicted value of ART coverage, $Avg(ART)_t$ is the regional average of ART coverage, $HIV_{i,2001}$ is the rate of HIV prevalence in country i in 2001, φ_0 is a constant, and φ_1 is the coefficient of interest, α_i represents country fixed effects, δ_i represents year fixed effects, and ε_1 is the error term.

In the second stage, I regress economic growth on the predicted ART coverage, controlling for other relevant factors. The final specification is therefore:

$$Y_{it} = \beta_0 + \beta_1 ART_{pred} + \alpha_i + \delta_t + X_\alpha + \varepsilon'_{it} \qquad (6)$$

Where Y represents the various measures of GDP (growth, ln(GDP), change in ln(GDP), GDP per capita at 2017 PPP), β_0 is the intercept, β_1 is the coefficient of interest representing the effect of ART coverage on GDP growth, and ε_2 is the error term.

The instrumental variable technique relies on the assumption that the constructed instrumental variable (ART_{pred}) is correlated with the endogenous variable (ART coverage) but uncorrelated with the error term in the second-stage regression. In other words, the instrument must cause variation in ART coverage but not have a direct effect on economic growth. This regionally predicted value of ART causes variation in the endogenous variable (actual ART) through two mechanisms: the variation introduced by the change in regional average ART coverage over years, and the variation introduced by the countries' HIV rates in 2001. The predicted value of ART does not have any direct link to economic growth. This is because the variation over time of the predicted value of ART is determined by a regional average of ART coverage. If a regional average of ART coverage increases, it is unlikely that this will have an effect on an individual country's economic growth.

The second concern is the likelihood of omitted variable bias in the specification of my model. Omitted variable bias (OVB) is a bias that is introduced by third-party variables not included in the specification that are determinants of the dependent variable (economic growth) and are correlated with the independent variable (ART coverage). Possible variables include existing government infrastructure that promotes economic activity and impacts the rollout of ART. Dealing with economic growth as a dependent variable introduces high potential for omitted variable bias, due to the many determinants of growth, many of which may be correlated with health. To address these concerns, I utilize controls in the form of entity (country) and time (year) fixed effects to account for all unobserved factors that may vary between countries but not across years, or vice versa.

Due to the addition of my proposed dual mechanism, whereby ART has an effect on economic growth through a direct health capital variable and an indirect educational human capital variable, as well as based on results from previous studies on this topic, my hypothesis is as follows: ceteris paribus, an increase in ART coverage is reflected in both an increase in health capital and an increase in educational human capital, driving an increase in economic growth. More specifically, due to the proposed dual mechanism, and the sustained expansion of ART across Sub-Saharan Africa since the periods studied by other economists, I predict that this effect will be larger than previous estimates.

However, I do expect there to be challenges in both establishing causality and realizing the results mentioned above. Firstly, the instrumental variable approach has severe limitations in its ability to provide accurate, valid results. Chief among these concerns are the assumptions that must hold in order for the IV to work. First: national trends must not be serially correlated, meaning the regional ART trend does not systematically change over time in a way that would affect country-specific outcomes differently. Second: economic growth must not cause dynamic adjustments, i.e. country-specific economic growth does not itself influence the regional trend in ART coverage or the country-specific composition (Mckenzie, 2018). In reality, if aid in the form of ART rollout and assistance is targeted at countries with low economic growth, the regional trend of ART may influence country-specific economic growth rates, invalidating the first assumption. Additionally, if countries with higher economic growth are able to drastically increase their ART coverage in a short time, thus affecting the regional average, this may invalidate the second assumption.

Additionally, the various efforts to catalyze economic growth on the continent, both domestic efforts and Official Development Assistance (ODA) from abroad may make it very difficult to isolate the effect of ART. Lastly, major global events such as the 2008 global financial crisis and the COVID-19 pandemic have greatly affected many indicators, including estimates of GDP. These factors may result in findings that are very different to what our model and previous literature indicate.

7. Results

This section details the results of various econometric specifications of the model and subsets of the sample. Table 2 displays the regression estimates of various specifications for the effect of ART on GDP growth, while Table 3 displays the regression estimates for the effect of ART on ln(GDP) as a measure of economic growth.

For all results presented in this section, “controls” take the form of country and year fixed effects. All regressions have standard errors clustered at the country level. For both dependent variables, I run a naive Ordinary Least Squares (OLS) regression with controls as defined above. Then, for each dependent variable, I run the two-stage least squares (2SLS) instrumental variable regression using the constructed instrument, with and without controls.

Table 2: Effect of ART on GDP Growth

VARIABLES	**OLS**	**IV**	**IV**
ART Coverage	0.063	-0.030**	0.062
	(0.044)	(0.012)	(0.060)
First Stage F-Statistic		89.9	29.15
N	840	840	840
R-squared	0.141	-0.009	0.169
Country & Year FE	**Yes**	**No**	**Yes**

Note: Results from three specifications of the regression with GDP growth being the dependent variable. F-statistic shown to highlight the strength of the instrument for the specifications using the IV. The inclusion of controls (country & year fixed effects) is shown. Standard errors are clustered by country shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 2 presents estimates of the effect of ART coverage on GDP growth as a measure of economic growth, for three specifications of the regression. The first is a specification employing ordinary least squares (OLS) estimation, with the standard controls: country and year fixed effects. This yields insignificant results. Second is an estimation using the instrumented value of ART coverage, without including any controls. This results in an estimate indicating that a 1% increase in ART coverage results in a 0.03% decrease in GDP growth, robust at the 5% confidence level. The final specification incorporates the IV, as well as country and year fixed effects as controls. It yields insignificant results.

For both of the specifications employing the IV, the F-statistic of the first stage of the 2SLS model is provided. In both cases, the high F-statistic (and subsequent low p-value) suggests that the instrument is a strong predictor of the endogenous variable. Moreover, under-identification and weak identification tests support the instrument's strength, with p-values close to zero. The weak-instrument-robust inference further confirms the joint significance of endogenous regressors, substantiating the reliability of the predicted ART coverage instrument in predicting the actual values of ART coverage. However, it is worth noting that, when the first stage includes controls, its validity seems to decrease as represented in a lower F-statistic but is still statistically significant. As discussed further below, this is not the case for all specifications of the model.

Table 3: Effect of ART on ln(GDP)

VARIABLES	**OLS**	**IV**	**IV**
ART Coverage	0.004***	0.011**	0.001
	(0.001)	(0.005)	(0.002)
First Stage F-Statistic		89.62	29.07
N	824	824	824
R-squared		-0.014	0.984
Country & Year FE	**Yes**	**No**	**Yes**

Note: Results from three specifications of the regression with ln(GDP) being the dependent variable. F-statistic shown to highlight the strength of the instrument for the specifications using the IV. The inclusion of controls (country & year fixed effects) is shown. Standard errors are clustered by country and shown in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3 provides estimates of the effect of ART on ln(GDP). ln(GDP) is used as the dependent variable in order to interpret results as a percentage change in the level of GDP, as the coefficient of ln(GDP) is an approximate percentage change in GDP and thus can be interpreted as the effect of ART on the level of GDP. Importantly, this is not the same as the interpretation of the results shown in Table 2. In Table 2, the coefficients can be interpreted as the effect of

ART on the growth rate of GDP. It is the rate at which GDP growth is accelerating or decelerating. However, the results presented in Table 3 must be interpreted as percentage changes in GDP (and therefore be a percentage rise or fall in the level of GDP), but it is not a change in the growth rate of GDP.

The first specification employs an OLS identification strategy and includes country and year-fixed effects as controls. In this case, a 1% increase in ART coverage results in a 0.4% increase in the level of GDP, and this is robust at the 1% confidence level. The second specification includes the IV as the identification strategy and does not include any control variables. It suggests that a 1% increase in ART coverage results in a 1.1% increase in the level of GDP, and is statistically significant at the 5% confidence level. Finally, the third specification, which includes the IV and country and year fixed effects yields statistically insignificant results.

Once again, for both of the specifications employing the IV, the F-statistic of the first stage of the 2SLS model is large and the p-values low, suggesting that the instrument is a strong predictor of the endogenous value of ART coverage.

In order to test the robustness of my results, I run various additional specifications of the regression. I decided to disaggregate the dataset by income group and region, due to the stark heterogeneity across these groups. However, there is a concern here: using the instrument constructed using the continental average of ART that varies by year would not be an accurate or effective identification strategy when the sample is limited to a subset of the continent. Therefore, I create instruments using the average ART rate by income group or region (four in each case) thus resulting in 8 specific instruments. Unfortunately, I was not able to get these instruments to work, likely because the sample size drops significantly when the sample is disaggregated by either of these ways. This is a limitation of current publicly available data.

Therefore, the main instrument was used and the sample was manually limited by adding restrictions on classifications to the econometric specification. All samples follow the IV specification and country and year fixed effects are included.

First, I disaggregate the sample into four income group classifications. I follow The World Bank (2003) atlas approach by using GDP per capita measured using PPP in international dollars (hereby "GDP") from 2001 for each observation's country to classify the country and corresponding observations into four categories[6]. 2001 is chosen as the year of classification as the level of GDP in 2001 would have had the largest impact on how countries reacted to the epidemic, by purchasing ART. The results of this are displayed in Table 4 (see appendix). In summary, the regression yielded no statistically significant results. Additionally, the F-statistic of the first stage is far lower than in my initial results, suggesting that the instrument is no longer effective when the sample is disaggregated, or that the disaggregation resulted in the groups containing too few observations to test the instrument.

Second, I disaggregate the sample by region. I follow The World Bank classifications of countries into East, West, Southern, and Central Africa (Open Knowledge Repository, 2021). The results of running this with the general instrument and limiting the sample by region are all statistically insignificant. Once again, the F-statistic of the first stage is low for multiple regions, indicating the inaccuracy of the instrument in predicting ART coverage within regions.

Note on the use of dependent variables:

An important distinction, and indeed addition, between previous studies, most notably (Tompsett, 2020), and my own, is the dependent variable used. Tompsett uses the change in log GDP per capita as the dependent variable in her headline results, interpreting them as growth

[6] Low-income countries are those which, in 2001, had a GDP of $745 or less, low-middle-income countries: between $746 - $2976, upper-middle-income countries: between $2,977 - $9,205, and high-income countries: $9,206 or above.

rates. While this is an acceptable and useful method when studying countries with low and stable rates of economic growth (and is, therefore, standard practice in the United States and much of Europe), the methodology does not hold when even a small number of the countries in question experience high rates (either positive or negative) of economic growth.

When macroeconomic variables are small and well-behaved, it is appropriate to approximate their growth using the variable's logged form, following:

$$\ln(Y_t) - \ln(Y_{t-1}) \approx \ln(1 + \gamma_t)$$
$$\approx \gamma_t$$

This approximation only yields relatively reliable results when the growth is small, but as growth increases, the approximation becomes less and less accurate. Therefore, it cannot hold when countries in a dataset experience large (positive or negative) rates of economic growth. This is the case in Sub-Saharan Africa over the years in my dataset. Of the 1148 observations between 2001 and 2019 (the sample that I include in the full regressions) that had recorded annual GDP growth rates, 444 reflected growth rates above 5%, 101 reflected growth rates above 10%, and 44 reflected growth rates above 20%. Additionally, the range of growth rates from -46% in South Sudan in 2012 to 63% in Equatorial Guinea in 2001, further illustrates the limiting use of the change in log GDP as a proxy for economic growth. While outside the scope of this paper, these extreme estimates have been linked to extreme events such as the struggle for independence and the discovery of natural resources respectively (Mawejje & McSharry, 2021, Frynas, 2004).

As a brief further investigation on the topic, I also ran the regression with average life expectancy at birth as the dependent variable. The result suggests that a 1% increase in ART coverage results in an increase in average life expectancy of 0.2 years, proving the efficacy of ART on its intended purpose.

8. Limitations

While I have taken multiple steps to estimate the causal effect of ART coverage on economic growth, there are limitations to this work. Economic growth is impacted by several factors, both internal and external to a country, and is subject to many idiosyncratic shocks. It is therefore difficult to isolate the effect of a specific factor on economic growth. The effect of policies or shocks may be felt long after they initially occur. It therefore becomes difficult to control for variables that have different lengths of impact. The heterogeneity across countries, in their economic structures, institutions, and policy environments adds complexity to cross-country estimations. The dynamic nature of the economy makes it challenging to predict or model.

The endogeneity that exists between economic growth and ART coverage presents a challenge to this estimation. While the IV approach reduces this concern, it is likely that the instrument is still endogenous to some degree with economic growth. Additionally, the strength of the instrument is not completely understood due to the decrease in strength when the sample is limited.

The size of the dataset is a limitation due to the inability to run region or income-specific instrumental variables as discussed in the results section. Access to more granular data would possibly allow for the use of different instruments to determine whether the effect ranges by region/income group or otherwise. Additionally, more granular data that captures demographic information would allow us to measure the impact of ART on various populations.

Finally, the inclusion of the country and year fixed effects, while successful at reducing the bias in the results, absorbs much of the variation, which is potentially the reason for the lack of significant results.

9. Conclusions

The majority of my findings indicate that there is no statistically significant effect of ART on economic growth. The only specifications that yield statistically significant results are either in a naive OLS specification or when no control variables are used.

Interestingly, when looking at the full sample, the only specifications that yield positive, statistically significant results is when the dependent variable is ln(GDP), which is interpreted as a percentage change in GDP. However, we don't see this same effect when using GDP growth, at least in the appropriately measured form, instead of a change in log that has been used in the literature. There are a number of reasons this could be. A possible reason could be that a significant proportion of the people in the dataset are subsistence farmers, and are therefore not included in the formal measurement of GDP growth. Therefore, while the economy might benefit from the immediate intervention, this does not persist for long enough to generate a change in GDP growth rates.

Another reason is that, especially during the beginning of the response to the epidemic, the ART that I expected to generate economic growth reached those in need too late, and therefore, while it may have led to an increase in GDP due to people living better and marginally longer lives, those who needed it did not survive and the effect of ART did not persist for long enough to influence the growth rate of GDP. Finally, using GDP growth to evaluate the impact of ART is socially "positive", while perhaps we should be focusing on the effect of ART on preventing the negative effects of HIV. Therefore, it may require us to rethink what we are measuring in order to hypothesize what may be happening in the real world.

While this study shows that ART coverage did not have a measurable effect on economic growth in the region, it is important to remember that this was not the intention of the expansion of the epidemic response. The results that I obtained with regard to life expectancy confirmed the effect of ART on allowing people to live longer lives. The importance of this ought not be overshadowed by the study of economic growth.

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Appendix

Table 4: The Impact of ART on GDP growth by Income Group

VARIABLES	Low-Income	Lower-Middle Income	Upper-Middle Income	High-Income
ART Coverage	0.031	0.035	0.091	0.246
	(0.193)	(0.107)	(0.057)	(0.239)
First Stage F-Statistic	0.34	12.45	8.66	87.49
Observations	43	493	209	95
R-squared	0.567	0.182	0.284	0.304
Country & Year FE	**Yes**	**Yes**	**Yes**	**Yes**

Note: Results from a 2SLS Instrumental Variable regression, with the instrument being a constructed predicted value of ART coverage, and all specifications including country and year fixed effects as controls. Standard errors are clustered by country shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: The Impact of ART on GDP growth by Region

VARIABLES	Central Africa	East Africa	West Africa	Southern Africa
ART Coverage	1.075	0.019	1.015	-0.067
	(2.356)	(0.038)	(0.748)	(0.878)
First Stage F-Statistic	0.11	25.83	0.83	0.38
Observations	95	176	152	379
R-squared	-0.774	0.403	-0.322	0.074
Country & Year FE	**Yes**	**Yes**	**Yes**	**Yes**

Note: Results from a 2SLS Instrumental Variable regression, with the instrument being a constructed predicted value of ART coverage, and all specifications including country and year fixed effects as controls. Standard errors are clustered by country shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Data Appendix

All data used in this study comes from the World Bank's World Development Indicators Dataset and are accurate at the time of submission (29th April 2024). The following operations are done in order to perform the regression analysis described in this paper:

- Key indicators including country name, country code, years, antiretroviral coverage, measures of GDP (ppp in 2017 international dollars & gdp growth), and HIV prevalence are downloaded and renamed accordingly.
- The dataset is transformed from short to long in order to perform panel regression analysis.
- In order to build the instrument, a variable is generated that represents the average of ART coverage across countries is taken by year, divided by 100 for scaling purposes.
- A variable is created for each observation that represents the observation's country's level of HIV in 2001, divided by 100 for scaling purposes.
- These two variables are multiplied to produce the "instrument" variable.
- For robustness checks, the dataset is divided by income group, according to the World Bank categories, which are as follows: Low income: GDP of $745 or less, low-middle-income: between $746 - $2976, upper-middle-income: between $2,977 - $9,205, and high-income countries: $9,206 or above.
- It is also divided by region according to the World Bank classifications.
- Region and income-group specific instruments are generated by taking averages of ART coverage by region/income group in the construction of the instrument. These are not used in this paper (too few observations to run) but will be important in future research.